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RESEARCH OVERVIEW: SOURCES OF INDOOR AIR POLLUTANTS

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16. ABSTRACT The paper briefly traces the history of air quality problems in residential, office, and public access buildings to show the evolution of indoor air quality (IAQ) concerns. It then briefly discusses sources of IAQ problems--both known and suspected--then reviews the current state of knowledge of emissions from these sources. It summarizes recent and current research in federal and private-sector organizations. Combustion sources, material sources (e.g., building materials and consumer products), activity sources (e.g., cleaning, maintenance, and cooking), and outside sources (e.g., outdoor air, soil gas, and contaminated groundwater) are used as categories to describe the complex problems being researched. The paper concludes with suggestions to building design, construction, and management professionals regarding prudent steps that can be taken to reduce potential IAQ problems from sources of greatest potential concern in today's residential, office, and public access buildings.

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a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B 15E
Buildings	Stationary Sources	13M 06H
Atmosphere Contamination Control	Indoor Air	08H
Combustion Products	Consumer Products	06K
Construction Materials	Soil Gas	21B
Maintenance		13C
Cookery		
Ground Water		

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ABSTRACT

The history of air quality problems in residential, office, and public access buildings is briefly traced, to show the evolution of indoor air quality (IAQ) concerns. Sources of IAQ problems, both known and suspected,are then briefly discussed. The current state of knowledge of emissions from these sources is then reviewed.

Recent and current research in federal and private-sector organizations is summarized. Combustion sources; material sources such as building materials and consumer products; activity sources such as cleaning, maintenance, and cooking; and outside sources such as outdoor air, soil gas, and contaminated groundwater are used as categories to describe the complex set of problems being researched.

The paper concludes with the author's suggestions to building design, construction, and management professionals regarding prudent steps that can be taken to reduce potential IAQ problems from sources of greatest potential concern in today's residential, office, and public access buildings.

HISTORY OF IAQ PROBLEMS

Indoor air quality (IAQ) has been a concern of building designers and owners for hundreds of years, but the nature of that concern has changed dramatically in the past twenty years. It is likely to change even more in the years to come, given recent findings on the composition of the air in buildings. Until about twenty years ago, building air quality was primarily dealt with by codes covering proper installation of heating devices and sufficient ventilation control of temperature, humidity, and carbon dioxide to meet comfort and odor criteria.

Two building-related trends started to shift the IAQ picture in the 1960s and 1970s: increased use of synthetic organic materials in buildings, furnishings, and consumer products; and decreased ventilation for energy conservation. These trends, coupled with rising public resistance to tobacco smoke in public buildings, introduced health concerns into the IAQ picture. These health concerns were mostly for respiratory effects and centered on a relatively small number of indoor air pollutants, most notably formaldehyde, nitrogen dioxide, asbestos, and tobacco smoke.

Within the past ten years, the nature of IAQ-related health concerns has broadened greatly. Complaints of irritating air quality in office buildings have been frequent enough that the terms "sick building syndrome" and "tight building syndrome" have been coined. Similarly, an increasing number of people are seeking treatment or advice on how to deal with apparent hypersensitivity to chemicals in the home. Field studies of IAQ in Europe and the United States have typically found diverse mixtures of chemicals in indoor air samples, most of which are organic compounds. These events, coupled with a growing

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public concern about "hazardous" chemicals in general (e.g., in foods and drinking water, from industrial accidents and waste dumps), have greatly increased the complexity of IAQ concerns. Health concerns are now starting to go beyond respiratory effects and include cancer, mucous membrane irritation, neurobehavioral effects such as memory impairment and loss of attention span, and perhaps suppression of immune responses. A substantial effort is also underway by several States and the U.S. Environmental Protection Agency (EPA) to regulate "toxic" air pollutants in the ambient (outdoor) air. Since the average person breathes far more indoor than outdoor air, indoor exposures to these toxics are of increasing interest.

Building industry professionals clearly need to be aware of these trends as they evolve further in the years to come. Whether IAQ problems are real or perceived, they will have an impact on the acceptability, and therefore marketability, of residential and commercial buildings. Results from research on sources of indoor air pollutants will be especially useful for guidance on such things as materials and appliances to specify or avoid, pretreatment of materials prior to installation, and pre-occupancy treatment of new or renovated buildings.

TYPES OF INDOOR SOURCES

Researchers have recently started to group indoor sources into four categories:

Source Type	Examples
Combustion	Smoking, unvented appliances (gas, kerosene), leaking vented appliances
Material	Building materials, furnishings, consumer products
Activity	Activities with physical involvement of people such as painting, polishing, spraying, cooking, use of machines or solvents
Outside	Infiltration of pollutants via outdoor air or soil gas, evaporation of contaminants from domestic water

In general, information on the pollutant emission rates from indoor sources is very limited. Combustion sources have been most completely characterized, but data are limited mostly to emissions of nitrogen dioxide (NO_2) and carbon monoxide (CO) from new appliances. Smoking is clearly a major source of respirable (fine) particles, but the emission rates of gaseous organic pollutants and their compositional changes with time have not been well characterized under room conditions. Data on emissions from material sources are much more limited. Pressed-wood products and urea formaldehyde foam insulation are known to be major sources of formaldehyde, and certain types of insulation and ceiling tiles, when in poor condition, can contribute asbestos fibers to indoor air.

Many field inspections of buildings have identified moist materials or standing water to be major sources of biological contaminants. Research on "outgassing," or evaporation, of organic vapors from materials is in its infancy, however. Activity sources are probably the least studied source type; although some building investigations have implicated copying machines and graphic arts activities as sources of irritating pollutants, indoor activities have not been studied systematically. Outside sources can clearly be major contributors where there is radon from soil gas and well water, automobile exhaust from poorly located ventilation intakes, or industrial waste organics from contaminated well water.

In short, research on indoor sources of air pollutants is in its very early stages; there is much to be done before we know the major sources of the pollutants of greatest concern, and what can be done to those sources to reduce their emissions.

RESEARCH CONCEPTS

Research on sources of indoor air pollutants involves measuring pollutant emission rates and determining the factors--such as indoor environmental conditions controllable by ventilation systems--that affect the emission rates and the dispersion of pollutants in buildings. The ultimate goal of such research is to determine the major sources of the

pollutants of greatest health concern and to characterize those sources in a way that will help determine the most cost-effective ways to control their emissions.

Intermediate objectives to that goal include: (1) developing procedures for making accurate and representative measurements of emissions; (2) developing emissions data for specific sources that can be used for design and interpretation of IAQ surveys of buildings, or determining major sources in investigations of individual buildings with air quality problems; and (3) developing a data base on sources and their emissions for use in guiding regulations and actions by building designers, owners, or occupants.

Partly because of the great chemical complexity of indoor air pollution caused by diverse and ever-changing sources, and partly because of the frequently private and personal nature of the issue, governmental regulations are likely to evolve much more slowly than public pressures for IAQ improvement. Therefore, much research on indoor sources is now becoming directed toward providing guidance to the private and public sectors. This guidance will basically be in three areas: guidance to product manufacturers and building designers on possibilities for conditioning of materials prior to installation in buildings; guidance to architects and builders on pre-occupancy conditioning (e.g., "flushing" or "baking") of new or renovated buildings; and guidance to the public on sources to avoid or use carefully, so that individuals can deal with chemical hypersensitivities or simply take prudent steps to reduce their exposure to air pollutants.

The underlying approach to attaining the research goal of determining "... the major sources of indoor pollutants of greatest health concern ..." is through source risk assessment, the key factors in which are:

SOURCE RISK ASSESSMENT

Source Emissions

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Dispersion and Removal

↓

Indoor Concentrations

↓

Exposure Time

↓

Exposure Amount

↓

Dose and Potency

↓

Health Risk

Measured pollutant emission rates from sources, modeled to predict indoor concentrations (or, alternatively, measured indoor concentrations modeled to obtain source contributions), are coupled first with people's activity patterns to obtain estimates of pollutant amounts to which people are exposed. Pathways of the pollutant in the body are then modeled to estimate amounts (doses) received over an appropriate time by an organ or body fluid of concern (e.g., lung, liver, or blood). With knowledge of pollutant potency and how the body will respond to such a dose, a health risk--either relative risk of a response compared to other sources or absolute risk of an effect--can be calculated.

While data from most research on emissions from indoor sources will be used in such risk assessments. it must be recognized that risk assessment itself is an emerging scientific discipline. Therefore, it is not yet realistic to expect that most decisions on important sources will be determined in this rather analytical manner. It is very important for building industry professionals to realize that pollutants (and therefore sources) of IAQ concern will emerge from unpredictable findings as well as from risk analysis for the next several years. It will be prudent for architects. engineers, and building owners to be alert to substances that rather suddenly attract the attention of the public and public health officials often because of dose-effects research findings from animal studies. Other substances to note are "air toxics" being evaluated by EPA and the states for outdoor air regulations. It seems likely that indoor pollutants like formaldehyde and radon are forerunners of many to come.

Several methods are used to study emissions from indoor sources. Basically, they are of three types: chamber studies, test house studies, and field studies. Chambers have the advantage of being highly controllable and cost-effective for testing many types of sources under many environmental or operating conditions. Dispersion and removal models are used to predict indoor concentrations.

Test houses, although still well instrumented and controlled, are more expensive and time-consuming to operate. Their advantages are primarily that they can be used to help validate dispersion models used in estimating indoor concentrations from chamber study data, since indoor concentrations are measured directly. rather than predicted. They can also be used to study activity sources (e.g., cooking) that are too complex for chamber studies.

Field studies. either in single occupied buildings or a series of them, are of limited use for developing a broad understanding of sources, since there is less control over the sources and factors influencing their emissions. Field studies are also very costly to conduct. Such studies are more commonly conducted to survey indoor air pollutants rather than sources. As better data become available on the rates and compositions of emissions from various source types field study data can be better interpreted to identify the major contributing sources.

Most research in the United States on sources of indoor air pollutants is currently being funded by the federal government. Primary funding organizations are EPA's Office of Research and Development. the Department of Energy (DOE), and the Consumer Product Safety Commission (CPSC). The National Aeronautics and Space Administration (NASA) supports extensive testing of emissions from materials to be used in spacecraft, as does the Navy for materials used in submarines.

Private-sector research is funded mainly by the Gas Research Institute (GRI) for combustion appliances, the Formaldehyde Institute and wood products industry for formaldehyde from pressed-wood products, and the tobacco industry for emissions from smoking. With the exception of GRI-funded work, results of most private sector research on indoor sources have not been published. A general summary of recent and current research. by source type, follows.

COMBUSTION SOURCES

Combustion appliances are being studied under projects funded by EPA. GRI CPSC, the Tennessee Valley Authority (TVA), and Bonneville Power Administration (BPA). GRI has for several years supported extensive testing of NO_2 and CO emissions from gas stoves and gas-fueled unvented space heaters by Illinois Institute of Technology Research Institute (IITRI) and Institute of Gas Technology (IGT). This work has been done to determine the contributions of natural-gas-fired appliances to indoor NO_2 and CO and to develop information for improved burner designs CPSC has funded similar testing of gas- and kerosene-fueled space heaters, both at Lawrence Berkeley Laboratory (LBL) and at their own test facility. Their work has been done to evaluate the health and safety hazards of unvented space heaters.

EPA has contracted with LBL to measure emission rates and compositions of organic emissions from kerosene space heaters. Radiant and convective heaters have been tested in a large chamber at LBL. Emissions were sampled in the chamber air: particles were collected on coated fiberglass filters, and semivolatile compounds were collected on adsorbent material

downstream of the filters. Extracts from both the filters and sorbent have been screened for a broad range of organic compounds by gas chromatography-mass spectrometry, analyzed for specific polycyclic organic compounds commonly found as products of incomplete combustion that are known or suspected carcinogens, and screened by bacterial mutagenesis assays to obtain a measure of potential carcinogenicity. Analytical results are now being analyzed to determine what further testing is needed.

TVA, CPSC, BPA, and EPA have funded studies of emissions from fireplaces and woodstoves into homes. Emissions of CO, NO_2, particles, and selected organic compounds associated with the particles have been measured. In addition, the EPA testing has included bacterial mutagenesis assays of extracts from particles in homes to obtain an indication of their carcinogenic potential. Data are now being analyzed, and further sampling will be conducted in the winter of 1986-87.

Very little has been reported to date on emission rates and compositions of sidestream smoke, other than from laboratory studies. A limited amount of large-chamber and in-home testing of emissions is now being funded by EPA. Emission rates and indoor concentrations of particles and semivolatile organic compounds are being measured, and bacterial mutagenesis assays are being made. This work is a part of a series of studies to determine the doses of constituents in sidestream (passive) smoke that are received by nonsmokers.

MATERIAL SOURCES

These sources are perhaps of greatest concern to building industry professionals, since they include the structural and HVAC materials, furnishing materials and fabrics, sealants, and coatings that go into new or renovated buildings. The primary types of pollutants of concern from such materials are:

- highly volatile organic compounds that can be present in concentrations of several hundred (or thousand) micrograms per cubic meter; they can cause various irritant responses in occupants or may have more subtle neurotoxic or even carcinogenic effects
- moderately volatile organic compounds (for example, pesticides, heavy constituents of solvents, and products of incomplete combustion) that can be present at much lower concentrations indoors; they may create subtle health effects and cause problems with equipment when they plate out on electronic components
- fibers that may cause respiratory and mucous membrane irritation
- biological contaminants that can cause a variety of allergic reactions or illnesses

Most of the material source research done to date in this country has been on formaldehyde emissions from pressed-wood products, especially the various types of particleboard. Regulations for formaldehyde from pressed-wood products used in mobile homes were established by the Department of Housing and Urban Development (HUD) in 1984. Prior to that time, research measurements at Oak Ridge National Laboratory (ORNL) and other laboratories were being made so as to understand how ventilation parameters like temperature, relative humidity, and air exchange rates affected emission rates of formaldehyde. Although such work continues at ORNL, the National Bureau of Standards (NBS), and Georgia Tech Research Institute, formaldehyde emission measurements have shifted more toward testing of products to determine compliance with the HUD standard.

Within the past two years, EPA and other organizations have started to look at other materials and emissions of other organic compounds. To date, procedures have been developed for testing emission rates and compositions. The procedures are largely an extension of experience from: formaldehyde emissions testing funded by CPSC, the Formaldehyde Institute, and the wood products industry; preliminary research in the late 1970s in Europe and at LBL

on organic compound emissions from various building materials; and NASA testing of compounds emitted from spacecraft materials. A wide variety of organic compounds and materials can be tested over ranges of temperature, relative humidity, ventilation rate, and time. The procedures have been designed for small chamber testing; that is, chambers with volumes of about 100 to 1000 liters. They can be applied, however, to large chambers. These procedures are likely to continue to evolve for the next several years. While they will be used mostly by researchers to help determine the major sources of indoor organic compounds, with modifications they can be used in more routine applications to test compliance with future standards that are likely to be developed by governmental agencies and manufacturers.

To date, a very limited amount of data on organic compound emissions has been produced. However, EPA and other organizations are gearing up to test a wide variety of building materials and furnishings over the next several years. Test results will be expressed as "emission factors" (e.g., micrograms of pollutant per hour per square meter of material). EPA, for example, in addition to doing such testing at its research facility in Research Triangle Park, NC, is also developing a computerized data base of such emission factors for use by anyone involved in building design, construction, and renovation.

These emission factors, plus a knowledge of the amount of material to be used in a building, coupled with estimates of air exchange and mixing rates in the building, can be used to estimate indoor concentrations from various sources. Judging the acceptability of these concentrations is the next step. Since specific guidance on acceptable concentrations for most compounds is not likely to be available for many years, building industry professionals will have to rely on general guidelines. At present, the most useful guideline on organic compounds comes from the work of Mølhave in Denmark. His experiments showed that, for a typical mixture of organic compounds found in indoor air, people start to become irritated at a total concentration of about 5 mg/m^3. Since in a typical building many sources contribute to the total load of organics in the air, it would seem prudent to try to keep the contribution of any one source below about 1 mg/m^3.

If the predicted contribution to indoor concentrations from one material source such as a wallcovering is quite high (e.g., greater than 1 mg/m^3 of total measured organic compounds), the prudent thing for the involved building design professionals would be to consider three options: (1) finding a substitute, low-emitting wallcovering; (2) preconditioning the wallcovering in a ventilated area such as a warehouse prior to installation; or (3) preconditioning the building prior to occupancy by ventilating under conditions that flush out the emissions. Data from chamber studies under a variety of environmental conditions will help determine the feasibility of options 2 and 3.

ACTIVITY SOURCES

Emissions from human activities such as cooking, painting, waxing, pesticide spraying, and use of machines or solvents have received even less attention to date than material sources. At the federal level, the greatest current emphasis is on methylene chloride emissions during the use of paint strippers and other household products. CPSC has funded LBL to measure emissions from paint stripping and other activities in a large chamber. EPA's Office of Toxic Substances is funding Midwest Research Institute to make similar measurements during use of a variety of household products such as paints, adhesives, and cleaners.

As IAQ research matures at the federal level, the amount of research on emissions from these sources is likely to increase and be closely coupled with research on material sources. Exposures during periods when products are being actively used (e.g., during painting) must be compared to longer-term exposures from emissions after the activity (e.g., from the painted wall) and from emissions off secondary materials (e.g., carpeting materials that have adsorbed some of the painting fumes, and are re-emitting them).

OUTSIDE SOURCES

These sources have in general not attracted much research attention. This is partly because of the building-specific nature of such problems (e.g., air intakes located close to traffic or parking garages). It is also partly due to

the predominant view that IAQ problems are mostly due to sources inside the building. Several studies have shown that domestic water highly contaminated with organics can lead to high indoor concentrations during cooking, showering, and other uses of hot water. A number of state regulatory agencies and universities are continuing to look at these sources and will be presenting and publishing results over the next several years.

Several other studies are also underway by EPA, TVA, and DOE to evaluate the contribution of infiltrated air to indoor concentrations of particles and carcinogenic substances in communities that have many woodstoves. Results from these studies are just beginning to be published.

Studies to measure the contribution of soil gas and well water to indoor radon concentrations in homes are a significant part of indoor air quality field studies funded by EPA, DOE, BPA,and several states and public utilities. These studies are finding that the primary source of radon is the entry of soil gas. In some homes with private wells, however, both soil gas infiltration control and water treatment are required to reduce indoor radon to satisfactory concentrations.

IMPLICATIONS FOR BUILDING INDUSTRY PROFESSIONALS

As can be seen from the above summary, researchers do not yet know enough about sources of indoor air pollution to produce a handbook. However, given the research that is now underway, just such a handbook may soon be a reasonable possibility. Results from current research could be presented in the following areas: source emission rates and compositions, dependency of emission rates on indoor environmental conditions, models for predicting indoor concentrations from emission rates, toxicities of indoor pollutants, control of IAQ by source controls, and control of IAQ by air cleaning. People involved in building design, construction, and regulation through codes or product standards could use such information to determine what sources to use in buidings, and how to specify and use them; what sources to avoid because of toxicities of their emissions or difficulties in controlling them; what ventilation practices are best for source control; and what air cleaning devices are effective. Through the combined efforts of researchers and practitioners represented by organizations such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the American Institute of Architects (AIA), a prototype handbook might be produced as early as 1990.

In the meantime, the limited amount of current information on indoor sources suggests that the following steps would be prudent for today's building industry professionals:

1. Stay tuned to organizations that publish and present information on IAQ topics. In addition to ASHRAE and AIA, the Air Pollution Control Association, the Consumer Federation of America, the National Association of Home Builders (and their Research Foundation), and the National Institute of Building Sciences are all expanding their efforts to disseminate information on IAQ topics. Articles on laboratory or field studies related to sources, source testing procedures, and investigation of problem buildings should be particularly useful. EPA's data base on indoor air pollution sources will be useful to those who are interested in detailed data on emissions.

2. Be concerned about specifying or installing building materials or furnishings that contain substantial amounts of volatile organic chemicals. Although the nose may still be the best indicator of potential irritant problems, some organic compounds of possible concern are not very odorous. As discussed earlier, it would be prudent to avoid any source that will create indoor concentrations above 1 mg/m^3 for more than a few days or weeks. In very rough terms, this means that material sources should be avoided or conditioned if they emit over 100 mg/h of organic compounds per 100 m^2 (1000 ft^2) of residential space with mixed and well distributed air, or sources emitting over 400 mg/h per 100 m^2 of typical office space with well mixed and distributed air.

3. Consider specifying maximum emission rates of pollutants from exposed structural materials, furnishings, office machines, and appliances. If the size of your business enables it, consider testing emission rates of materials or appliances to be used, or contract with a firm to do such testing.

4. Design heating, ventilating, and air-conditioning systems to exhaust air from the vicinity of indoor sources, rather than disperse the pollutants throughout the building.

5. Avoid building designs having areas where excessive moisture can lead to growth of biological contaminants, and provide easy access for maintenance of ventilating system components that might collect moisture.

In the years ahead, more substantial recommendations will be available from ongoing research to characterize indoor sources, their emissions, and their controllability. A bibliography of representative literature appears below for those interested in details of recent research programs. Source-related papers contained in this Proceedings should also be consulted.

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